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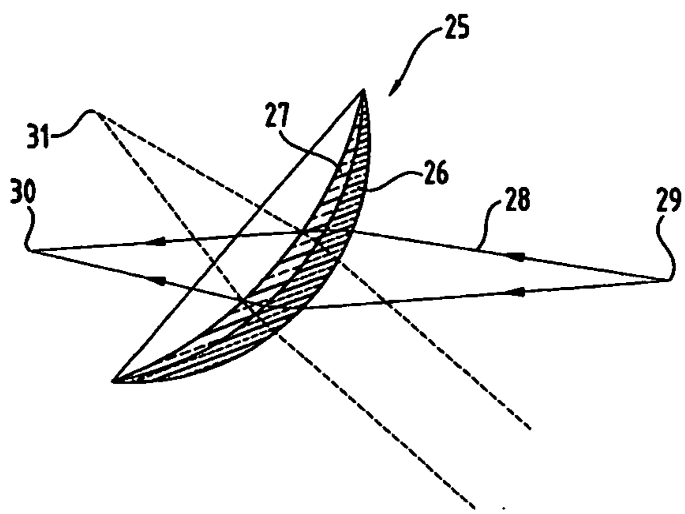

(57) Abstract

The invention provides an optical lens having a combination volume holographic optical element that provides a diffractive optical power. The optical lens has a programmed activating angle in which the holographic optical element provides a diffractive optical power. The invention also provides a method for producing a multilayer holographic element suitable for the optical lens.

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COMPOSITE HOLOGRAPHIC MULTIFOCAL LENS

The present invention relates to a multifocal lens containing a holographic element and providing at least two optical powers.

Various bifocal lens design concepts for ophthalmic lenses, which are placed on or in the eye to correct visual defects, e.g., contact lenses and intraocular lenses, are available. One conventional bifocal ophthalmic lens design is the concentric simultaneous vision type. Another conventional bifocal ophthalmic lens design is the diffractive simultaneous vision type.

Yet another conventional bifocal ophthalmic lens design is the translating type. A translating lens has two distinct localized viewing sections that have different optical powers. The position of the bifocal lens on the eye must shift from one section to the other when the wearer wishes to see objects that are located at a distance different from the objects currently in focus.

Recently, actively controllable approaches for providing a bifocal function in an ophthalmic lens have been proposed. A simultaneous vision type bifocal lens having sectionally applied thermochromic coatings is an example.

There remains a need for an ophthalmic lens that reliably provides multifocal functions without the deficiencies of prior art multifocal lenses. There also remains a need for a suitable process for producing such a multifocal lens.

There is provided in accordance with the present invention an optical lens having a volume holographic optical element, which provides an optical power, and the volume holographic optical element is a combination or composite holographic element. The optical lens has a programmed activating angle in which the holographic optical element provides a diffractive optical power. The invention also provides a method for producing a multilayer holographic element suitable for the optical lens. The method has the steps of providing a first source light beam; splitting the first source light beam into first and second light beams; providing a recordable holographic element having oppositely located first and second surfaces, wherein the surfaces are flat, concave or convex; directing the first and second light beams to the first and second surfaces, respectively, of the recordable holographic element; providing a second source light beam; splitting the second source light beam into third and fourth light beams; and directing the third and fourth light beams to the first and second surfaces, respectively, of the recordable holographic element, wherein the first and third

light beams and the second and fourth light beams have proper phase relationships to record grating structures, desirably volume grating structures, in the recordable holographic element. The invention additionally provides a sequential method for producing a composite holographic element. The sequential method has the steps of providing a first polymerizable or crosslinkable fluid optical material in a first mold; recording a first volume grating structure in the optical material, thereby forming a first non-fluid HOE layer; providing a second mold, wherein the second mold has a cavity volume larger than the first HOE layer and holds the first HOE layer on one surface thereof; providing a second polymerizable or crosslinkable fluid optical material in the second mold over the first HOE layer; and recording a second volume grating structure in the second optical material, thereby forming a second non-fluid HOE layer, wherein the first and second HOE layers are coherently joined.

The present invention provides an activatable multifocal optical lens which has a combination volume holographic optical element. The combination volume holographic optical element allows the optical element to have a small angular change between the activated and inactivated states, as well as reduces dispersion and chromatic aberrations.

Fig. 1 illustrates an active ophthalmic lens of the present invention.

Fig. 2 illustrates the diffraction function of the holographic optical element for an active lens of the present invention.

Fig. 3 illustrates an active ophthalmic lens of the present invention.

Fig. 4 illustrates the transmission function of the holographic optical element.

Fig. 5 illustrates the diffraction function of the holographic optical element when the element is activated.

Fig. 6 illustrates an exemplary method for producing the holographic optical element.

Fig. 7 illustrates the optical power of the holographic optical element.

Figs. 8-8B illustrate a combination holographic optical element of the present invention.

Fig. 9 illustrates a spectacle composite lens of the present invention.

Fig. 10 illustrates an exemplary method for producing a combination HOE.

Fig. 11 illustrates another exemplary method for producing a combination HOE.

The present invention provides active multifocal ophthalmic lenses. The present invention additionally provides active multifocal lenses for spectacles. Hereinafter, the term

"optical lenses" is used to indicate both ophthalmic lenses and spectacle lenses, unless otherwise indicated. The active optical lens of the invention provides more than one optical power. More specifically, the lens provides at least one optical power and at least one additional optical power that can be activated. Unlike conventional bifocal lenses, the present active multifocal lens can be actively and selectively controlled to provide one desired optical power at a time without or substantially without optical interferences from the other optical powers of the lens.

The active optical lens contains a holographic optical element (HOE), and suitable HOEs for the active optical lens are transmission volume HOEs. A volume HOE contains interference fringe patterns that are programmed or recorded as a periodic variation in the refractive index of the optical material. The periodic variation in refractive index creates planes of peak refractive index, i.e., volume grating structure, within the optical material. The planes of interference fringe pattern in the HOE is further discussed below.

Turning to Fig. 1, the figure illustrates an exemplary active bifocal lens 10 of the present invention. It is to be noted that the invention is disclosed herein in reference to a bifocal optical lens for illustration purposes although the active optical lens of the present invention can have more than two optical powers. The lens 10 is a contact lens having a first optical element 12 and an HOE 14. The HOE 14 is embedded or encapsulated in the first optical element 12 to form the composite lens 10 such that the HOE 14 moves in conjunction with the lens 10. The first optical element 12 provides a first optical power, which corrects ametropia, e.g., myopia. Alternatively, the first optical element 12 can be a plano lens that functions as a carrier for the HOE 14. As for the HOE 14, the optical element is designed to modify the path of light only when the light enters the HOE 14 at a pre-programmed angle or within a pre-programmed angle range, i.e., activating angle, that activates the optical element. Accordingly, when the light enters at an angle that is outside the activating angle, the HOE 14 completely or substantially completely transmits the incoming light without significantly modifying or without modifying the path of the light. Alternatively stated, the HOE 14 may act as a plano lens except when the incident angle of the incoming light comes within the pre-programmed activating angle. When the HOE 14 is activated, the fringe patterns or volume grating structure programmed in the HOE 14 modifies the path of the light to provide an optical power that is different from the first optical power of the lens 10. In addition to the activatable optical power, the HOE 14 may also provide an optical power that results from the shape of the HOE 14 and the refractive index of the composition of the HOE 14. Such additional optical power complements the

first optical material to provide the first optical power of the active lens 10 when the incoming light enters the lens 10 at an angle that does not active the HOE 14. The term "activating angle" as used herein indicates an incident angle of incoming light, which is defined by the angle formed by the advancing direction of incoming light and the axis normal to the HOE surface, that satisfies the Bragg condition such that the incoming light is diffracted by the interference fringe grating structure of the HOE, which is further discussed below. It is to be noted that the activating angle does not have to be a single value and can be a range of angles. When the Bragg condition is met, up to 100% of incoming light can be coherently diffracted.

Fig. 2 further illustrates the function of the HOE 14 of the bifocal active lens 10 of Fig. 1. The z-axis, which is normal to the planar surface of the HOE 14, and the advancing direction of the incoming light R form the incident angle σ. When the incoming light R enters the HOE 14 at an incident angle that is within the activating angle of the HOE 14, the light R is diffracted by the pre-programmed interference fringe pattern, i.e., the volume grating structure, of the HOE 14 and exits the HOE 14 as outgoing light S with an exiting angle ρ which is different from the incident angle σ.

Figure 3 illustrates another embodiment of the active bifocal lens of the present invention. The bifocal active lens 16 is a composite lens which has a first optical lens 17 and an HOE lens 18, which completely covers the first optical lens 17. Alternatively, the HOE lens 18 can be of a size that covers only the pupil of the eye. The first optical lens 17 and the HOE lens 18 can be fabricated separately and joined, e.g., adhesively or thermally. Alternatively, the first optical lens 17 and the HOE lens 18 can be sequentially or simultaneously fabricated one over the other such that a composite lens is produced. This sequential or simultaneous approach is particularly suited when the first optical lens and the HOE lens are produced from one basic material or two chemically compatible materials. Although the active lens 16 is illustrated with a lens having an inner half first optical lens and an outer half HOE lens, other combinations of various optical elements can be produced in accordance with the present invention.

Yet another embodiment of the active bifocal lens is a non-composite active HOE bifocal lens. In this embodiment, the active HOE bifocal active lens is produced from an optical material that forms an HOE. The combination of the shape of the active lens and the refractive index of the HOE material provides a first optical power and the programmed volume grating structure in the HOE lens provides a second optical power. This non-

composite active HOE lens embodiment is particularly suitable when the HOE material employed is a biocompatible material and, thus, does not adversely interact with the ocular tissues in the eye. The term "biocompatible material" as used herein refers to a polymeric material that does not deteriorate appreciably and does not induce a significant immune response or deleterious tissue reaction, e.g., toxic reaction or significant irritation, over time when implanted into or placed adjacent to the biological tissue of a subject. Exemplary biocompatible materials that can be used to produce an HOE suitable for the present invention are disclosed in U.S. Pat. No. 5,508,317 to Beat Müller and International Patent Application No. PCT/EP96/00246 to Mühlebach, which patent and patent application are herein incorporated by reference and further discussed below. Suitable biocompatible optical materials are highly photocrosslinkable or photopolymerizable optical materials which include derivatives and copolymers of a polyvinyl alcohol, polyethyleneimine, or polyvinylamine.

The present HOE is designed or programmed to have one activating angle or a range of activating angles within which the HOE is activated, and the HOE diffracts the incoming light to focus the light on a desired location. Figs 4 and 5 illustrate the function of the HOE 21 of the composite active lens 20, which contains an HOE lens element that is programmed to focus light originating from a near distance. When light 22 from a distant object enters the lens at an angle that does not activate the HOE 21, the light 20 is focused in accordance with the optical power of the first optical element 23 of the lens 10, in combination with the optical power of the crystalline lens of the eye (which is not shown), to a focal point 24 on the retina of the eye, more specifically on the fovea. For example, the first optical element 23 can have a corrective power in the range between +10 diopters and - 20 diopters. It is to be noted that the HOE lens 21 may have an inherent optical power that comes from the shape of the HOE lens 21 and the refractive index of the HOE composition. Consequently, the HOE lens 21 may contribute to the refractive optical power of the active lens 20. Notwithstanding, hereinafter, the inherent optical power of the HOE lens 21 is ignored in order to simplify the illustration of the diffractive function of the present HOE lens since the inherent optical power can be easily factored into the teaching of the present invention. When the HOE lens 21 is not activated, the HOE lens 21 does not interfere with the light 22 from traveling the normal refractive path caused by the first optical lens element 23. However, when the light enters the HOE lens 21 at an angle that activates the HOE lens 21 (i.e., enters within the activating angle), the light is diffracted by the HOE lens 21. As illustrated in Figure 5, when the incoming light enters the active lens 25 at an

angle that activates the HOE lens 26, the lens, in conjunction with the first optical lens 27 and the crystalline lens of the eye, focuses the light on the retina, more specifically on the fovea. For example, light 28 originating from a near object 29 forms an image 30 on the fovea, when the light enters the HOE lens 26 at an angle that is within the programmed activating angle.

The incident angle of incoming light with respect to the active bifocal lens, more specifically to the HOE portion of the active lens, can be changed by various means. For example, the active lens can be tilted to change the incident angle of the incoming light, i.e., the wearer of the lens can change the incident angle of the light by looking down while maintaining the position of the head. Alternatively, the active lens may have a position controlling mechanism that can be actively controlled by the wearer of the lens with one or more muscles in the eye. For example, the active lens can be shaped to have a prim ballast such that the movement of the lens can be controlled with the lower eyelid. It is to be noted that the activating angle of the active lens 25 illustrated in Fig. 5 is exaggerated to more easily explain the present invention, and thus, the activating angle of the active lens does not have to be as large as the tilted angle illustrated in Fig. 5. In fact, HOEs suitable for the present invention can be programmed to have a wide range of different activating angles in accordance with HOE programming methods known in the holographic art. Accordingly, the degree of movement required for the active lens to switch from one optical power to another can be easily changed depending on the design criteria and the needs of each lens wearer.

Although the active lens of the present invention provides more than one optical power, the active lens forms clearly perceivable images that are focused by one optical power at a time. Consequently, the active lens does not produce blurred or fogged images, unlike conventional bifocal lenses such as concentric simultaneous bifocal lenses. Returning to Fig. 5, when the active lens 25 is positioned to view a near object 29 (i.e., the incident angle of the light originating from the object 29 is within the activating angle of the HOE lens 26), the light from the object 29 is focused by the HOE lens 26, in conjunction with the first optical lens 27 and the crystalline lens of the eye, onto the fovea 30. At the same time, the incident angle of the light originating from distant objects is not within the activating angle of the active lens 25. Accordingly, the path of the incoming light from distant objects is not modified by the HOE lens 26, but the path of the incoming light from distant objects is modified, i.e., refracted, by the first optical lens 27 and the crystalline lens of the eye. The incoming light from the distant objects is, therefore, focused to forms an

image at an area 31 which is outside the fovea. Consequently, the focused images of the near and distant objects are not concentrically or axially aligned. It has been found that the image, which is formed outside the fovea 31, is not clearly perceived by the wearer of the active lens 25 and is easily disregarded as peripheral vision. Consequently, the wearer of the active lens 25 is able to clearly view the near object 29 without having blurring interferences from the light originating from distant objects.

Similarly, when the active lens is position to view a distant object, for example, as illustrated in Fig. 4, the light 22 from distant objects enters the lens at an angle outside the activating angle of the HOE 21. Therefore, the path of the light is not affected by the HOE 21, and is only affected by the first optical element 23 and the crystalline lens of the eye, thereby forming an image of the distant object on or near the fovea 24. At the same time, the light originating from a near object is diffracted and focused by the HOE 21 and is projected onto an area outside the fovea. Accordingly, the wearer of the active lens clearly views the distant object without significant interferences.

The non-blurring advantage of the present active lens is a result of the design of the active lens that utilizes the inherent anatomy of the eye. It is known that the concentration of the retinal receptors outside the fovea is drastically lower than that in the fovea. Consequently, any image focused substantially outside of the fovea is not clearly perceived since the image is undersampled by the retina and easily disregarded by the brain of the lens wearer as peripheral vision or images. In fact, it has been found that the visual acuity of a human eye drops to about 20/100 for objects only 8° off the line of sight. In the above-described actively controlling manner, the present active lens provides clear images from one optical power at a time by utilizing the inherent anatomy of the eye. Utilizing the inherent retinal receptor anatomy of the eye and the ability to program different ranges of activating angles in the HOE lens, the present active lens uniquely and selectively provides clear images of objects that are located at different distances. In contrast to various simultaneous bifocal lenses, the active lens provides unimpeded clear images, and in contrast to translating bifocal lenses, the active lens can be easily designed to require only a small movement of the lens to selectively provide images from different distances.

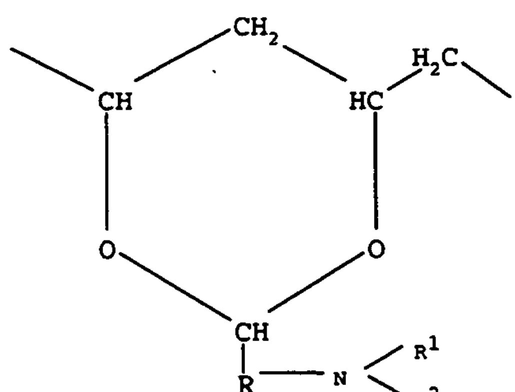
HOEs suitable for the present invention can be produced, for example, from a polymerizable or crosslinkable optical material, especially a fluid optical material. Suitable polymerizable and crosslinkable HOE materials are further discussed below. Hereinafter, for illustration purposes, the term polymerizable material is used to indicate both

polymerizable and crosslinkable materials, unless otherwise indicated. An exemplary process for producing an HOE of the present invention is illustrated in Fig. 6. Point-source object light 32 is projected to a photopolymerizable optical material 33 (i.e., photopolymerizable HOE), and simultaneously collimated reference light 34 is projected to the photopolymerizable HOE 33 such that the electromagnetic waves of the object light 32 and the reference light 34 form interference fringe patterns, which are recorded in the polymerizable material as it is polymerized, thereby forming a volume grating structure in the lens 33. The photopolymerizable HOE 33 is a photopolymerizable material that is polymerized by both the object light and the reference light. Preferably, the object light and the reference light are produced from one light source, using a beam splitter. The two split portions of the light are projected toward the HOE 33, in which the path of the object light portion of the split light is modified to form a point-source light 32. The point-source object light 32 can be provided, for example, by placing a conventional convex optical lens some distance away from the photopolymerizable HOE 33 so that the light is focused on a desirable distance away from the HOE 33, i.e., on the point-source light position 32. A preferred light source is a laser source, more preferred is a UV laser source. Although the suitable wavelength of the light source depends on the type of HOE employed, preferred wavelength ranges are between 300nm and 600nm. When the photopolymerizable HOE 33 is fully exposed and polymerized, the resulting HOE contains a pattern of refractive index modulation, i.e., the volume grating structure 35. In addition, when a fluid polymerizable optical material is used to produce the HOE, the light source transforms the fluid optical material to a non-fluid HOE while forming the volume grating structure. The term "fluid" as used herein indicates that a material is capable of flowing like a liquid.

Turning to Fig. 7, the polymerized HOE 36 has a focal point 38 which corresponds to the position of the point-source object light 32 of Fig. 6 when light 39 enters the HOE 36 from the opposite side of the focal point and matches or substantially matches the reversed path of the collimated reference light 34 of Fig. 6. Figs 6 and 7 provide an exemplary method for producing an HOE having a positive corrective power. As can be appreciated, HOEs having a negative corrective power can also be produced with the above-described HOE production set up with small modifications. For example, a convergent object light source that forms a focal point on the other side of the HOE away from the light source can be used in place of the point-source object light to produce an HOE having a negative corrective power. In accordance with the present invention, active multifocal lenses having various corrective powers can be readily and simply produced to correct various ametropic

conditions, e.g., myopia, hyperopia, prebyopia, regular astigmatism, irregular astigmatism and combinations thereof. For example, the corrective powers of the HOEs can be changed by changing the distance, position and/or path of the object light, and the activating angle of the HOEs can be changed by changing the positions of the object light and the reference light.

In accordance with the present invention, suitable HOEs can be produced from polymerizable and crosslinkable optical materials that can be relatively rapidly photopolymerized or photocrosslinked. A rapidly polymerizable optical material allows a periodic variation in the refractive index can be created within the optical material, thereby forming a volume grating structure while the optical material is being polymerized to form a solid optical material. An exemplary group of polymerizable optical materials suitable for the present invention is disclosed in U.S. Pat. No. 5,508,317 to Beat Müller. A preferred group of polymerizable optical materials, as described in U.S. Patent No. 5,508,317, are those that have a 1,3-diol basic structure in which a certain percentage of the 1,3-diol units have been modified to a 1,3-dioxane having in the 2-position a radical that is polymerizable but not polymerized. The polymerizable optical material is preferably a derivative of a polyvinyl alcohol having a weight average molecular weight, M_w, of at least about 2,000 that, based on the number of hydroxy groups of the polyvinyl alcohol, comprises from about 0.5% to about 80% of units of formula I :



(I)

wherein:

R is lower alkylene having up to 8 carbon atoms,

R^1 is hydrogen or lower alkyl and

R^2 is an olefinically unsaturated, electron-attracting, copolymerizable radical preferably having up to 25 carbon atoms. R^2 is, for example, an olefinically unsaturated acyl radical of formula R^3—CO—, in which

R^3 is an olefinically unsaturated copolymerizable radical having from 2 to 24 carbon atoms, preferably from 2 to 8 carbon atoms, especially preferably from 2 to 4 carbon atoms.

In another embodiment, the radical R^2 is a radical of formula II

$$—CO—NH—(R^4—NH—CO—O)_q—R^5—O—CO—R^3 \quad \text{(II)}$$

wherein

q is zero or one;

R^4 and R^5 are each independently lower alkylene having from 2 to 8 carbon atoms, arylene having from 6 to 12 carbon atoms, a saturated divalent cycloaliphatic group having from 6 to 10 carbon atoms, arylenealkylene or alkylenearylene having from 7 to 14 carbon atoms, or arylenealkylenearylene having from 13 to 16 carbon atoms; and

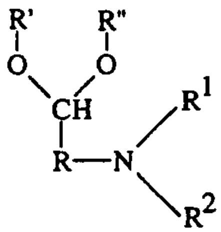
R^3 is as defined above.

Lower alkylene R preferably has up to 8 carbon atoms and may be straight-chained or branched. Suitable examples include octylene, hexylene, pentylene, butylene, propylene, ethylene, methylene, 2-propylene, 2-butylene and 3-pentylene. Preferably lower alkylene R has up to 6 and especially preferably up to 4 carbon atoms. Methylene and butylene are especially preferred. R^1 is preferably hydrogen or lower alkyl having up to seven, especially up to four, carbon atoms, especially hydrogen.

As for R^4 and R^5, lower alkylene R^4 or R^5 preferably has from 2 to 6 carbon atoms and is especially straight-chained. Suitable examples include propylene, butylene, hexylene, dimethylethylene and, especially preferably, ethylene. Arylene R^4 or R^5 is preferably phenylene that is unsubstituted or is substituted by lower alkyl or lower alkoxy, especially 1,3-phenylene or 1,4-phenylene or methyl-1,4-phenylene. A saturated divalent cycloaliphatic group R^4 or R^5 is preferably cyclohexylene or cyclohexylene-lower alkylene, for example cyclohexylenemethylene, that is unsubstituted or is substituted by one or more methyl groups, such as, for example, trimethylcyclohexylenemethylene, for example the divalent isophorone radical. The arylene unit of alkylenearylene or arylenealkylene R^4 or R^5 is preferably phenylene, unsubstituted or substituted by lower alkyl or lower alkoxy, and the alkylene unit thereof is preferably lower alkylene, such as methylene or ethylene, especially methylene. Such radicals R^4 or R^5 are therefore preferably phenylenemethylene or methylenephenylene. Arylenealkylenearylene R^4 or R^5 is preferably phenylene-lower alkylene-phenylene having up to 4 carbon atoms in the alkylene unit, for example phenyleneethylenephenylene. The radicals R^4 and R^5 are each independently preferably

lower alkylene having from 2 to 6 carbon atoms, phenylene, unsubstituted or substituted by lower alkyl, cyclohexylene or cyclohexylene-lower alkylene, unsubstituted or substituted by lower alkyl, phenylene-lower alkylene, lower alkylene-phenylene or phenylene-lower alkylene-phenylene.

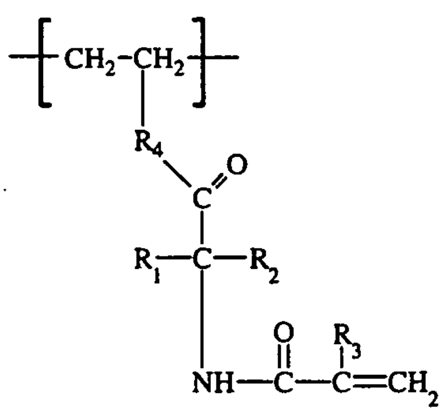
The polymerizable optical materials of the formula I be produced, for example, by reacting a polyvinylalcohol with a compound III,



(III)

wherein R, R^1 and R^2 are as defined above, and R' and R" are each independently hydrogen, lower alkyl or lower alkanoyl, such as acetyl or propionyl. Desirably, between 0.5 and about 80% of the hydroxyl groups of the resulting the polymerizable optical material are replaced by the compound III.

Another group of exemplary polymerizable optical materials suitable for the present invention is disclosed in International Patent Application No. PCT/EP96/00246 to Mühlebach. Suitable optical materials disclosed therein include derivatives of a polyvinyl alcohol, polyethyleneimine or polyvinylamine which contains from about 0.5 to about 80%, based on the number of hydroxyl groups in the polyvinyl alcohol or the number of imine or amine groups in the polyethyleneimine or polyvinylamine, respectively, of units of the formula IV and V:



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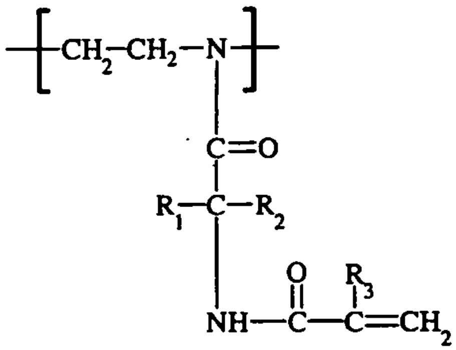
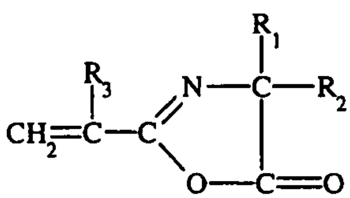


(V)

wherein R_1 and R_2 are, independently of one another, hydrogen, a C_1-C_8 alkyl group, an aryl group, or a cyclohexyl group, wherein these groups are unsubstitued or substituted; R_3 is hydrogen or a C_1-C_8 alkyl group, preferably is methyl; and R_4 is an -O- or -NH- bridge, preferably is -O-. Polyvinyl alcohols, polyethyleneimines and polyvinylamines suitable for the present invention have a number average molecular weight between about 2000 and 1,000,000, preferably between 10,000 and 300,000, more preferably between 10,000 and 100,000, and most preferably 10,000 and 50,000. A particularly suitable polymerizable optical material is a water-soluble derivative of a polyvinyl alcohol having between about 0.5 to about 80%, preferably between about 1 and about 25%, more preferably between about 1.5 and about 12%, based on the number of hydroxyl groups in the polyvinyl alcohol, of the formula IV that has methyl groups for R_1 and R_2, hydrogen for R_3, -O- (i.e., an ester link) for R_4.

The polymerizable optical materials of the formulae IV and V can be produced, for example, by reacting an azalactone of the formula VI,



(VI)

wherein R_1, R_2 and R_3 are as defined above, with a polyvinyl alcohol, polyethyleneimine or polyvinylamine at elevated temperature, between about 55°C and 75°C, in a suitable organic solvent, optionally in the presence of a suitable catalyst. Suitable solvents are those which dissolve the polymer backbone and include aproctic polar solvents, e.g., formamide, dimethylformamide, hexamethylphosphoric triamide, dimethyl sulfoxide, pyridine, nitromethane, acetonitrile, nitrobenzene, chlorobenzene, trichloromethane and

dioxane. Suitable catalyst include tertiary amines, e.g., triethylamine, and organotin salts, e.g., dibutyltin dilaurate.

Another group of HOEs suitable for the present invention can be produced from conventional volume transmission holographic optical element recording media. As with the above-described polymerizable materials for HOEs, object light and collimated reference light are simultaneously projected onto an HOE recording medium such that the electromagnetic waves of the object and reference light form interference fringe patterns. The interference fringe patterns, i.e., volume grating structure, are recorded in the HOE medium. When the HOE recording medium is fully exposed, the recorded HOE medium is developed in accordance with a known HOE developing method. Suitable volume transmission holographic optical element recording media include commercially available holographic photography recording materials or plates, such as dichromatic gelatins. Holographic photography recording materials are available from various manufacturers, including Polaroid Corp. When photographic recording materials are used as the HOE, however, toxicological effects of the materials on the ocular environment must be considered. Accordingly, when a conventional photographic HOE material is used, it is preferred that the HOE be encapsulated in a biocompatible optical material. Useful biocompatible optical materials for encapsulating the HOE include optical materials that are suitable for the first optical element of the present active lens, and such suitable materials are further discussed below.

As is known in the ophthalmic art, an ophthalmic lens should have a thin dimensional thickness to promote comfort of the lens wearer. Accordingly, a dimensionally thin HOE is preferred for the present invention. However, in order to provide an HOE having a high diffractive efficiency, the HOE has to be optically thick, i.e., the light is diffracted by more than one plane of the interference fringe pattern. One way to provide an optically thick and dimensionally thin HOE is programming the interference fringe pattern in a direction that is slanted towards the length of the HOE. Such slanted volume grating structure renders the HOE to have a large angular deviation between the incident angle of the incoming light and the exiting angle of the exiting light. However, an HOE having a large angular deviation may not be particularly suitable for an optical lens. For example, when such an HOE is used in an ophthalmic lens and the HOE is activated, the active line of sight is significantly bent away from the normal straight line of sight. As a preferred embodiment of the present invention, this angular limitation in designing an HOE lens is addressed by utilizing a multilayer combination HOE, especially a bilayer HOE. Figure 8 illustrates an exemplary

multilayer HOE 40 of the present invention. Two dimensionally thin HOEs having a large angular deviation are fabricated into a combination HOE to provide a dimensionally thin HOE that has a small angular deviation. The combination HOE 40 has a dimensionally thin first HOE 42 and a thin second HOE 44. The first HOE 42 is programmed to diffract the incoming light such that when light enters the HOE at an activating angle α, the light exiting the HOE 42 forms an exiting angle β, which is larger than the incident angle α, as shown in Fig. 8A. Preferably, the first HOE has a thickness between about 10 μm and about 100 μm, more preferably between about 20 μm and about 90 μm, most preferably between about 30 μm and about 50 μm. The second HOE 44 is programmed to have a activating incident angle β that matches the exiting angle β of the first HOE 42. In addition, the second HOE 44 is programmed to focus the incoming light to a focal point 46 when the light enters within the activating angle β. Fig. 8B illustrates the second HOE 44. Preferably, the second HOE has a thickness between about 10 μm and about 100 μm, more preferably between about 20 μm and about 90 μm, most preferably between about 30 μm and about 50 μm.

When the first HOE 42 is placed next to the second HOE 44 and the incoming light is directed at an angle that corresponds to the activating angle α of the first HOE 42, the light exiting the multilayer HOE focuses the light to the focal point 46. By utilizing a multilayer combination HOE, a dimensionally thin HOE having a high diffractive efficiency and a small deviation angle can be produced. In addition to the high diffractive efficiency and small angular deviation advantages, utilizing a multilayer HOE provides other additional advantages, which include correction of dispersion aberration and chromatic aberration. A single HOE may produce images having dispersion and chromatic aberrations since visual light consists of a spectrum of electromagnetic waves having different wave lengths and the differences in wavelengths may cause the electromagnetic waves to diffract differently by the HOE. It has been found that a multilayer, especially bilayer, HOE can counteract to correct these aberrations that may be produced by a single layer HOE. Accordingly, a multilayer combination HOE is preferred as the HOE component of the active lens.

The multilayer combination HOE can be produced from separately produced HOE layers. The layers of the combination HOE are fabricated and then permanently joined, adhesively or thermally, to have a coherent contact. Alternatively, the combination HOE can be produced by recording more than one layer of HOEs on an optical material. Preferably, the multilayers of HOEs are recorded simultaneously. As a preferred embodiment, Fig. 10 illustrates a simultaneous recording method for producing a

combination HOE. The simultaneous recording arrangement 60 has a first light section and a second light section. The first light section has a first light source 62, a beamsplitter 64, a first mirror 66, a second mirror 68 and an optical material holder 70 which holds a polymerizable optical material. The light source 62, preferably a laser source, provides a beam 63 of light to the beamsplitter 64, and the beamsplitter 64 splits the beam 63 into two portions, preferably two equal portions. The two mirrors 66 and 68 are placed on two opposite sides of the beamsplitter 64 such that one split portion of the light beam, which continues the original path of the light beam 63, is directed to the first mirror 66 and the reflected portion is directed to the second mirror 68. The two mirrors direct the two light beams to enter the optical material in proper phase to record a volume grating structure from one side (i.e., the first flat surface) of the optical material holder 70.

The second light section has the same components as the first light section, i.e., a light source 72, a beamsplitter 74, a third mirror 76, a fourth mirror 78, and the optical material holder 70 which is shared with the first light section. The components of the second light section are arranged such that the split light beams enter the optical material, which is held by the optical material holder 70, from the opposite side of the first light section (i.e., the second surface of the holder) and in proper recording phase to record a volume grating structure from the second surface. The resulting polymerized optical element has two HOE layers.

As another preferred embodiment, Fig. 11 illustrates a second simultaneous recording method for producing a combination HOE. The second simultaneous recording arrangement 80 also has a first light section and a second light section. A bidirectionally emitting light source 71 provides coherent light beams to the two light sections. For the first light section, a light beam 83 from the light source 81 is reflected by a mirror 82 to a beamsplitter 84. The light beam 83 is split into two beams, preferably two equal portions, 85 and 87. The first beam 85 is allowed to travel the path of the original light beam 83, and the second beam 87 is directed to the opposite direction of the first beam 85. Both beams 85 and 87 are reflected by mirrors 86 and 88, respectively, and directed to an optical material holder 90. The optical material holder 90, which is a mold that holds a polymerizable optical material and has two flat or relatively flat surfaces, is positioned such that the two light beams 85 and 87 enter the optical material holder 90 from the opposite flat surfaces. Based on the illustration of Fig. 11, the first light beam 85 enters the optical material holder 90 from the right flat surface and the second light beam 87 enters the optical material holder 90 from the left flat surface.

The second light section also has the same components as the first light section – a mirror 92, a beamsplitter 94, a pair of mirrors 96 and 98, and the optical material holder 90, which is shared by the two light sections. The beamsplitter 94 of the second light section provides two light beams, i.e., a third light beam 95 and a fourth light beam 97, and the pair of mirrors 96 and 98 direct the light beams to enter the optical material holder 90 from the two flat surfaces. The first light beam 85 and the third light beam 95 are coherent and enter the optical material holder 90 in proper phase to record a volume grating structure in the optical material held in the holder 90, starting from the optical material located near the entering flat surface. The second light beam 87 and the fourth light beam 97 are also coherent and enter the optical material holder 90 from the other flat surface. The two light beams are in proper phase to record a volume grating structure in the optical material, starting from the optical material located near the entering flat surface. Preferably, the recording arrangement 80 additionally has light polarizers that polarize the first and third light beams to one coherent and polarized direction and the second and fourth light beams to another coherent and polarized direction such that the two pairs of light beams do not interfere with each other. In addition, for both of the above simultaneous recording methods, it is preferred that each pair of light beams has sufficient polymerizing influence on only one half of the optical material in the optical material holder, which are located closer to the entrance flat surface, thereby efficiently forming two distinct HOE layers. It is to be noted that although the present invention is illustrated above with a optical material holder or mold having two flat surfaces that receive the recording light beams, the surfaces can have other configurations including concave and convex surfaces and combinations thereof.

The simultaneous recording methods are particularly suitable for producing HOEs from the above disclosed polymerizable or crosslinkable optical materials. A polymerizable or crosslinkable optical material is placed in a light-transmissible enclosed optical material holder, i.e., a mold. Suitable molds for the simultaneous recording arrangement include conventional lens molds for producing contact lenses. A typical lens mold is produced from a transparent or UV transmissible thermoplastic and has two mold halves, i.e., one mold half having the first surface of the lens and the other mold half having the second surface of the lens.

When the optical material is placed in a mold, the recording arrangement is activated to polymerize the optical material and simultaneously record two volume grating structures in the optical material from the two opposite surfaces defined by the two mold

halves. Optionally, after the optical element forms the volume grating structures, the recording light set up is turned off and the optical element is subjected to a post-curing step to ensure that all of the fluid optical material in the mold is fully polymerized. For example, the reference light source alone is turned on to post-cure the optical material.

With a simultaneous recording method, a combination HOE can be produced relatively simply and a large variety of HOEs having different activating angles can be produced by changing the positions and angles of the mirrors and beamsplitters in the arrangement. Preferably, an effective amount of a light absorbing compound (e.g., a UV absorber when UV laser is used) is added to the polymerizable optical material in the mold such that the light beams entering from one side of the mold (i.e., the first surface defined by the mold) does not have a strong polymerizing influence on the optical material that is located closer to the second side of the mold. The addition of the light absorber ensures that distinct layers of HOEs are formed and the polymerizing light entering from one side of the mold does not interfere with the polymerizing light entering from the other side. The effective amount of a light absorber varies depending on the efficacy of the light absorber, and the amount of the light absorber should not be so high as to significantly interfere with proper polymerization of the optical material. Although preferred light absorbers are biocompatible light absorbers, especially when the present invention is used to produce ophthalmic lenses, non-biocompatible light absorbers can be used. When a non-biocompatible light absorber is used, the resulting HOE can be extracted to remove the light absorber after the HOE is fully formed.

Exemplary UV absorbers suitable for the optical materials include derivatives of o-hydroxybenzophenone, o-hyroxyphenyl salicylates and 2-(o-hydroxyphenyl) benzotriazoles, benzenesulfonic acid and hindered amine. Particularly suitable UV absorbers include topically acceptable UV absorbers, e.g., 2,4-dihydroxybenzophenone, 2,2'-dihydroxy-4,4-dimethoxybenzophenone, 2-hydroxy-4-methoxybenzophenone and the like. An exemplary embodiment uses between 0.05 and 0.2 wt% of a UV absorber, preferably a benzenesulfonic acid derivative, e.g., benzenesulfonic acid, 2,2-'([1,1'-biphenyl]-4,4'-diyldi-2,1-ethenediyl)bis-, disodium salt.

As another embodiment of the present invention, the combination HOE can be produced by a sequential recording method. A closed mold assembly, which has a pair of two mold halves, containing a fluid polymerizable or crosslinkable optical material is subjected to a volume grating structure recording process, and then the mold assembly is opened while leaving the formed HOE layer adhered to the optical surface of one mold half.

An additional amount of the polymerizable optical material or a chemically compatible second polymerizable optical material is placed over the first HOE layer. Then, a new pairing mold half, which has a larger cavity volume than the previously removed mold half, is mated with the mold half that has the first HOE layer. The new mold assembly is subjected to a second volume grating structure recording process to form a second HOE layer over the first HOE layer. The resulting HOE is a combination HOE having two sequentially formed and adjoined HOE layers.

In accordance with the present invention, HOEs of the present invention preferably have a diffraction efficiency of at least about 70 %, more preferably at least about 80 %, most preferably at least 95 %, over all or substantially all wavelengths within the visible spectrum of light. Especially suitable HOEs for the present invention have a diffraction efficiency of 100% over all wavelengths of the spectrum of visible light. However, HOEs having a lower diffraction efficiency than specified above can also be utilized for the present invention. Additionally, preferred HOEs for the present invention have a sharp transition angle between the activated and non-activated stages, and not gradual transition angles, such that activation and deactivation of the HOE can be achieve by a small movement of the active lens and that no or minimal transitional images are formed by the HOE during the movement between the activated and deactivated stages.

As for the first optical material of the active lens, an optical material suitable for a hard lens, gas permeable lens or hydrogel lens can be used. Suitable polymeric materials for the first optical element of the active ophthalmic lens include hydrogel materials, rigid gas permeable materials and rigid materials that are known to be useful for producing ophthalmic lenses, e.g., contact lenses. Suitable hydrogel materials typically have a crosslinked hydrophilic network and hold between about 35 % and about 75 %, based on the total weight of the hydrogel material, of water. Examples of suitable hydrogel materials include copolymers having 2-hydroxyethyl methacrylate and one or more comonomers such as 2-hydroxy acrylate, ethyl acrylate, methyl methacrylate, vinyl pyrrolidone, N-vinyl acrylamide, hydroxypropyl methacrylate, isobutyl methacrylate, styrene, ethoxyethyl methacrylate, methoxy triethyleneglycol methacrylate, glycidyl methacrylate, diacetone acrylamide, vinyl acetate, acrylamide, hydroxytrimethylene acrylate, methoxy methyl methacrylate, acrylic acid, methacrylic acid, glyceryl ethacrylate and dimethylamino ethyl acrylate. Other suitable hydrogel materials include copolymers having methyl vinyl carbazole or dimethylamino ethyl methacrylate. Another group of suitable hydrogel materials include polymerizable materials such as modified polyvinyl alcohols,

polyethyleneimines and polyvinylamines, for example, disclosed in U.S. Patent No. 5,508,317, issued to Beat Müller and International Patent Application No. PCT/EP96/01265. Yet another group of highly suitable hydrogel materials include silicone copolymers disclosed in International Patent Application No. PCT/EP96/01265. Suitable rigid gas permeable materials for the present invention include cross-linked siloxane polymers. The network of such polymers incorporates appropriate cross-linkers such as N,N'-dimethyl bisacrylamide, ethylene glycol diacrylate, trihydroxy propane triacrylate, pentaerythtritol tetraacrylate and other similar polyfunctional acrylates or methacrylates, or vinyl compounds, e.g., N-m,ethylamino divinyl carbazole. Suitable rigid materials include acrylates, e.g., methacrylates, diacrylates and dimethacrylates, pyrolidones, styrenes, amides, acrylamides, carbonates, vinyls, acrylonitrieles, nitriles, sulfones and the like. Of the suitable materials, hydrogel materials are particularly suitable for the present invention.

In accordance with the present invention, the first optical element and the HOE can be laminated or the HOE can be encapsulated in the first optical element to form the active lens, when one of the composite active lens embodiments is practiced. In addition, when an ophthalmic active lens is produced using a non-biocompatible HOE, the HOE preferably is encapsulated in the first optical element such that the HOE does not make direct contact with the ocular environment since the HOE may adversely affect the long-term corneal health. Alternatively, as discussed above, the active lens can be produced from a biocompatible HOE such that an HOE can provide both diffractive and refractive functions, e.g., the first and second optical powers, of the active lens.

Figure 9 illustrates another embodiment of the present invention. A bifocal spectacle lens 50 is formed by laminating a layer of a first optical material having a first optical power 52, which provides an optical power, and a layer of an HOE 54, which provides a second optical power. The two layers are fabricated separately and then joined, e.g., thermally or adhesively. The composite lenses can be subsequently machined to fit a spectacle frame to provide a pair of bifocal glasses. The first optical material 52 is a conventional optical material that has been used to produce eyeglasses, e.g., glass, polycarbonate, polymethylmethacrylate or the like, and the HOE is any holographic optical material that can be programmed to focus the incoming light, as previously described. Alternatively, the bifocal spectacle lens can be produced from a shaped HOE such that the optical shape of the HOE provides a refractive power when the HOE is not activated and the volume grating structure of the HOE provides a diffractive power when it is activated.

The present multifocal optical lens can be actively and selectively controlled to provide one desired optical power at a time without or substantially without optical interferences from the other optical powers of the lens, unlike conventional bifocal lenses. In addition, the programmable nature of the HOE of the active lens makes the lens highly suitable for correcting ametropic conditions that are not easily accommodated by conventional corrective optical lenses. For example, the active lens can be programmed to have corrective measures for the unequal and distorted corneal curvature of an irregular astigmatic condition by specifically designing the object and reference light configurations.

The present invention is further illustrated with the following examples. However, the examples are not to be construed as limiting the invention thereto.

Examples

Example 1: About 0.06 ml of the Nelfilcon A lens monomer composition is deposited in the center portion of a female mold half, and a matching male mold half is placed over the female mold half, forming a lens mold assembly. The male mold half does not touch the female mold half, and they are separated by about 0.1 mm. The lens mold halves are made from quartz and are masked with chrome, except for the center circular lens portion of about 15 mm in diameter. Briefly, Nelfilcon A is a product of a crosslinkable modified polyvinyl alcohol which contains about 0.48 mmol/g of an acryamide crosslinker. The polyvinyl alcohol has about 7.5 mol % acetate content. Nelfilcon A has a solid content of about 31 % and contains about 0.1 % of a photoinitiator, Durocure® 1173. The closed lens mold assembly is placed under a laser set up. The laser set up provides two coherent collimated UV laser beams having 351 nm wavelength, in which one beam is passed through a optical convex lens so that the focal point is formed at 500 mm away from the lens mold assembly. The focused light serves as a point-source object light. The angle formed between the paths of the object light and the reference light is about 7°. The set up provides an HOE having an added corrective power of 2 diopters. The lens monomer composition is exposed to the laser beams having about 0.2 watts for about 2 minutes to completely polymerize the composition and to form interference fringe patterns. Since the lens mold is masked except for the center portion, the lens monomer exposed in the circular center portion of the mold is subjected to the object light and the reference light and polymerized. The mold assembly is opened, leaving the lens adhered to the male mold half. About 0.06 ml of the Nelfilcon A lens monomer composition is again deposited in the

center portion of the female mold half, and the male mold half with the formed lens is placed over the female mold half. The male and female mold halves are separated by about 0.2 mm. The closed mold assembly is again exposed to the laser set up, except that the optical convex lens is removed from the object light set up. The monomer composition is again exposed to the laser beams for about 2 minutes to completely polymerize the composition and to form a second layer of interference fringe patterns.

The resulting composite lens has an optical power based on the shape of the lens and the refractive index of the lens material and an activatable additional corrective power of +2 diopters.

<u>Example 2:</u> Example 1 is repeated except that the laser set up for the second layer is modified. For the second layer, the grating structure recording set up for the first layer is repeated. The resulting HOE is a combination HOE and has two layers of volume grating structures. When the cross section of the HOE is studied under an electron microscope, two distinct layers of volume grating structures are clearly observed.

<u>Example 3:</u> An HOE programming set up discussed above in conjunction with Fig. 11 is used to produce a combination HOE. The programming set up has equally configured object light and reference light sections. The light source provides a collimated UV laser beam having 351 nm wavelength, and the light source provides sufficient energy to deliver 1 to 2 mW/cm^2 when each light beam enters the optical material holder. Two flat quartz slides, which are spaced apart by about 50 lm, are used as the optical material holder, and a sufficient amount of a crosslinkable optical material is placed in the optical material to from a circular cylinder having a 14 mm diameter. The crosslinkable optical material used is UV absorber-modified Nelfilcon A. Nelfilcon A is modified by adding 0.1 wt% of Stilbene™ 420, which is available from Exitron and is Benzenesulfonic acid, 2,2'-([1,1'-biphenyl]-4,4'-diyldi-2,1-ethenediyl)bis-, disodium salt. The optical material in the mold is irradiated from both sides by the object and reference laser beams for 4 minutes to record two layers of volume grating structures from both flat surface of the mold.

The resulting combination HOE is a flexible hydrogel HOE that has two distinct HOE layers. Each of the two HOE layers occupies about half of the thickness of the hydrogel HOE.

What is claimed is:

1. An optical lens comprising a first optical element and a transmission volume holographic optical element, wherein said first optical element provides a first optical power at a first focal point, and said holographic optical element provides a second optical power at a second focal point, wherein said holographic optical element is a combination holographic optical element and diffracts up to 100% of incoming light when the Bragg condition is met.

2. The optical lens of claim 1 wherein said combination holographic optical element has two layers of holographic elements.

3. The optical lens of claim 2 wherein said two layers of holographic elements are separately fabricated layers.

4. The optical lens of claim 2 wherein said two layers of holographic elements are simultaneously recorded layers.

5. The optical lens of claim 1 is biocompatible.

6. The optical lens of claim 1 is a contact lens.

7. The optical lens of claim 1 is a spectacle lens.

8. A method for producing a bilayer holographic element, which comprising the steps of:
   h) providing a first source light beam,
   i) splitting said first source light beam into first and second light beams,
   j) providing a recordable holographic element having oppositely located first and second surfaces, said surfaces being flat, concave or convex,
   k) directing said first and second light beams to said first and second surfaces, respectively, of said recordable holographic element,
   l) providing a second source light beam,
   m) splitting said second source light beam into third and fourth light beams, and

n) directing said third and fourth light beams to said first and second surfaces, respectively, of said recordable holographic element, wherein

said first and third light beams have proper phase relationships to record a grating structure from said first surface of said recordable holographic element, and said second and fourth light beams have proper phase relationships to record a grating structure from said second surface of said recordable holographic element

9. The method of claim 8 wherein said recordable holographic element comprises a crosslinkable or polymerizable optical material.

10. The method of claim 9 wherein said recordable holographic element is a fluid optical material that forms a non-fluid optical material when exposed to said light beams.

11. The method of claim 9 wherein said recordable holographic element further comprises a UV absorber.

12. The method of claim 9 wherein said method further comprises the step of post curing the recorded optical element with said reference beams.

13. An optical lens comprising a transmission volume holographic optical element, said optical element having a programmed activating angle, wherein said optical element provides a first optical power for light entering said optical element at an angle outside said activating angle and provides a second optical power for light entering said optical element at an angle within said activating angle, and wherein said holographic optical element is a combination holographic optical element.

14. The optical lens of claim 13 wherein said optical lens is an ophthalmic lens.

15. The optical lens of claim 13 wherein said optical lens is a contact lens.

16. The optical lens of claim 13 wherein said combination holographic optical element has at least two layers of holographic elements.

17. A method for producing a composite holographic element, which comprising the steps of:
    q) providing a first polymerizable or crosslinkable fluid optical material in a first mold;
    r) recording a first volume grating structure in said optical material, thereby forming a first non-fluid HOE layer;
    s) providing a second mold, said second mold having a cavity volume larger than said first HOE layer and holding said first HOE layer on one surface thereof;
    t) providing a second polymerizable or crosslinkable fluid optical material in said second mold over said first HOE layer; and
    u) recording a second volume grating structure in said second optical material, thereby forming a second non-fluid HOE layer, wherein

    said first and second HOE layers are coherently joined.

18. The method of claim 17 wherein said first and second fluid optical materials are the same fluid optical material.

19. The method of claim 17 wherein said first and second fluid optical materials are chemically compatible optical materials.

20. A method for producing a bilayer holographic element, which comprising the steps of:
    t) providing a recordable holographic element having oppositely located first and second surfaces,
    u) providing a first source light beam,
    v) splitting said first source light beam into first and second light beams,
    w) directing said first and second light beams to said first surface of said recordable holographic element,
    x) providing a second source light beam,
    y) splitting said second source light beam into third and fourth light beams, and
    z) directing said third and fourth light beams to said second surface of said recordable holographic element, wherein

    said first and second light beams have proper phase relationships to record a grating structure from said first surface of said recordable holographic element, and said third

and fourth light beams have proper phase relationships to record a grating structure from said second surface of said recordable holographic element.

Fig. 1

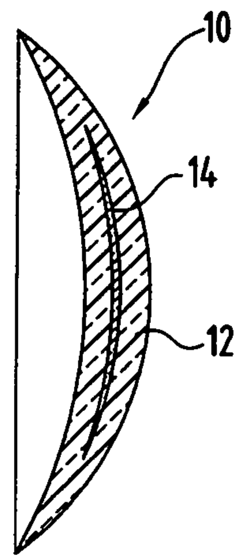
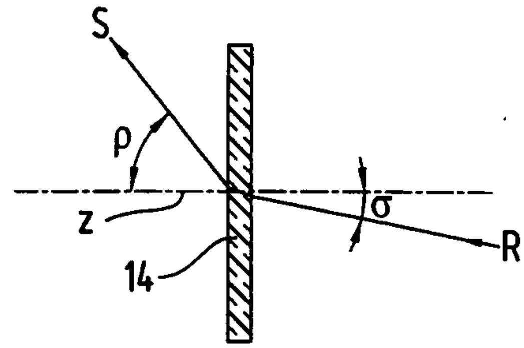


Fig. 2



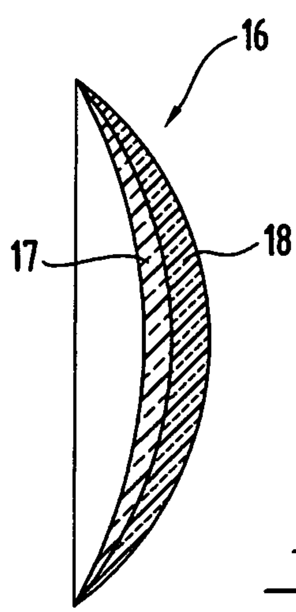


Fig. 3

Fig. 4

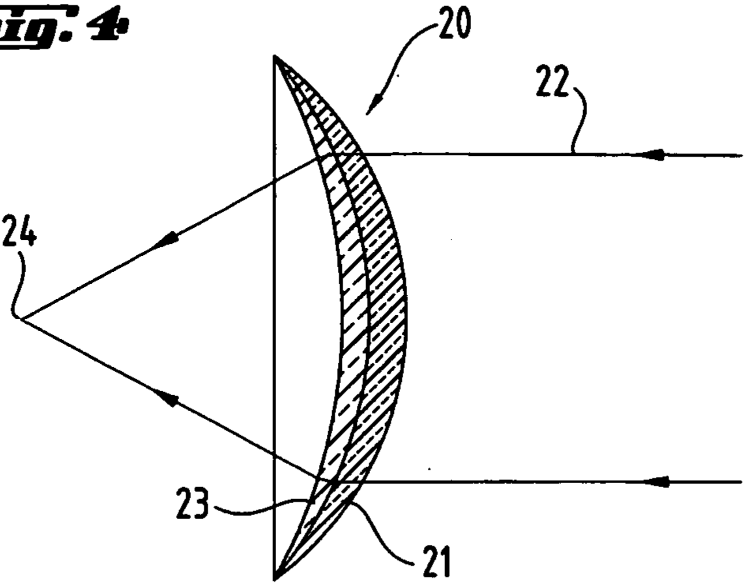


Fig. 5

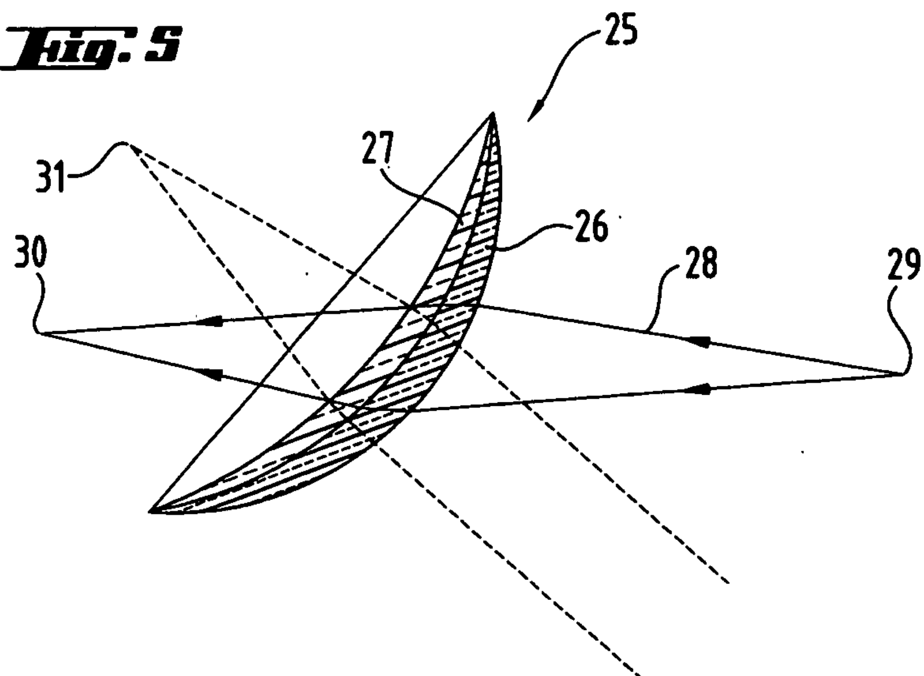


Fig. 6

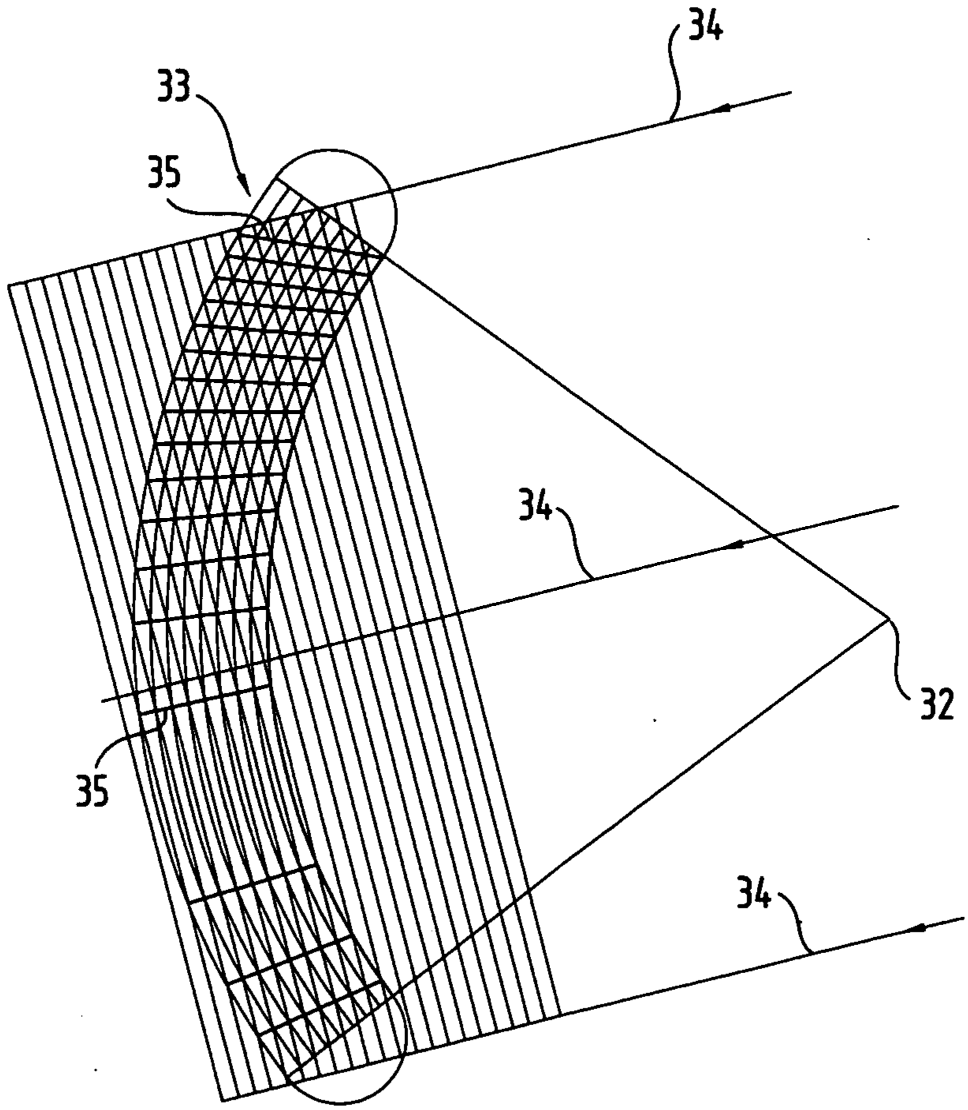


Fig: 7

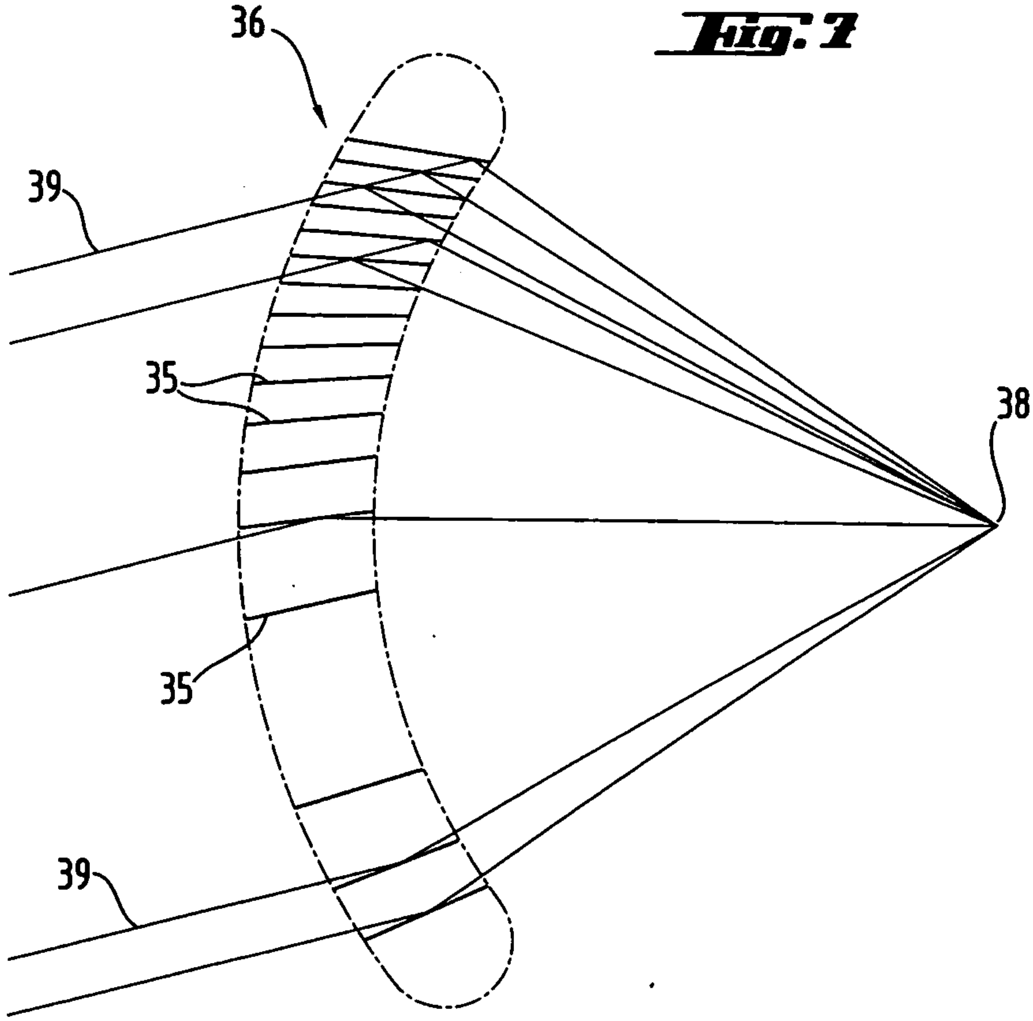


Fig. 8

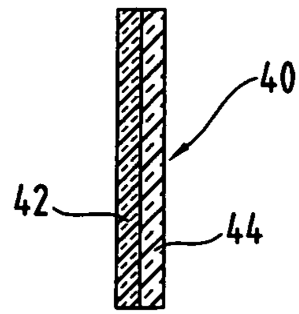


Fig. 8 A

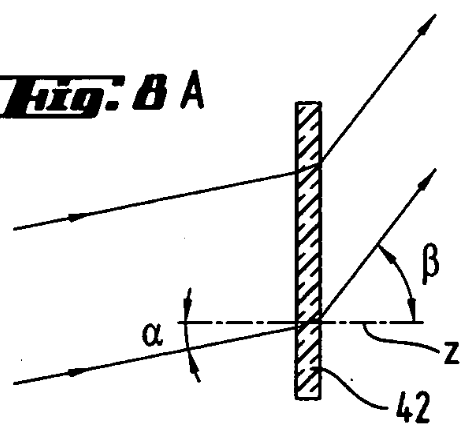


Fig. 8 B

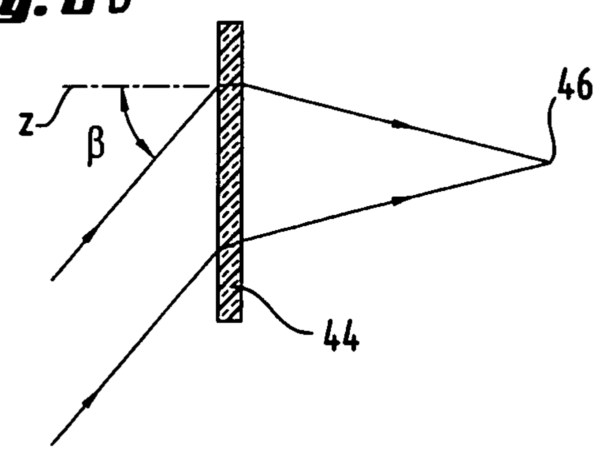


Fig. 9

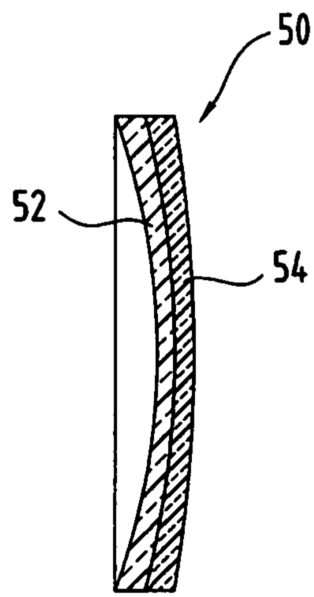


Fig. 10

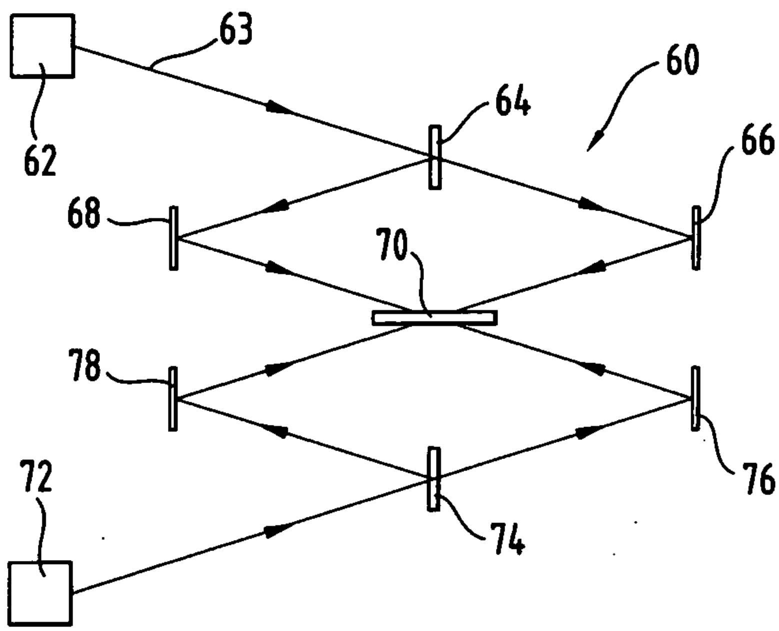

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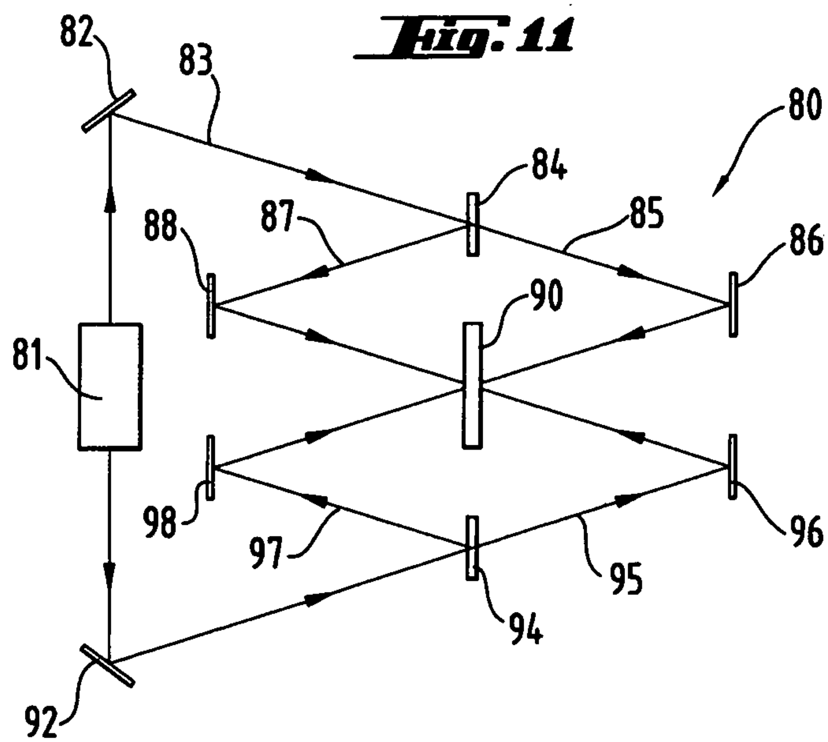
Fig. 11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INTERNATIONAL SEARCH REPORT

Internat J Application No
PCT/EP 98/08466

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G02C7/04 G02C7/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G02C G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 97 10527 A (UNIV CALIFORNIA) 20 March 1997 see page 7, paragraph 1 - page 8, paragraph 2	1,8,13, 17,20
A	US 4 642 112 A (FREEMAN MICHAEL H) 10 February 1987 see column 4, line 59 - column 6, line 68; figures 1-5	1,8,13, 17,20
A	US 4 206 965 A (MCGREW STEPHEN P) 10 June 1980 see claim 1	1,8,13, 17,20

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
3 June 1999	14/06/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Sarneel, A

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/EP 98/08466

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9710527 A	20-03-1997	NONE	
US 4642112 A	10-02-1987	AU 546822 B	19-09-1985
		AU 8260182 A	04-11-1982
		EP 0064812 A	17-11-1982
		GB 2101764 A,B	19-01-1983
		IE 53199 B	31-08-1988
		JP 1593901 C	14-12-1990
		JP 2016890 B	18-04-1990
		JP 58005715 A	13-01-1983
US 4206965 A	10-06-1980	CA 1089262 A	11-11-1980
		DE 2738025 A	02-03-1978
		FR 2363140 A	24-03-1978
		GB 1586096 A	18-03-1981
		JP 1345138 C	29-10-1986
		JP 53027046 A	13-03-1978
		JP 61012267 B	07-04-1986
		US 4411489 A	25-10-1983